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DYNAMIC COMBUSTION STUDIES USING ADVANCED OPTICAL DIAGNOSTICS

VOLUME II : Tabulated Data

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Computer models of turbulent mixing and combustion suffer from many limitations, deficiencies, and errors. To evaluate and refine them, an experimental research program was started (a) to develop a combustion test facility and optical diagnostics, (b) to perform turbulent mixing and combustion experiments, and (c) to provide a data base for modeling needs.

In Volume I of this final report, experimental studies on turbulent mixing and combustion were described. In Volume II, bench-mark quality data recorded in these experiments are documented for modeling needs. Specifically, data are tabulated for three variable-density, non-reactive turbulent mixing experiments: (1) 2-D Mixing Layer,

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19. Abstract (Continued)

(2) 2-D Slot Jet/Centerbody, and (3) Round Jet, and for two turbulent combustion experiments: (1) Scalar Fluctuations in Premixed Flames, (2) Conical Flame Stabilizer.

These data may be used to evaluate and refine modeling codes of turbulent mixing and combustion processes.

PREFACE

This final report was submitted by the University of Dayton Research Institute (UDRI) under Contract No. F33615-82-C-2255, sponsored by the U.S. Air Force Wright Aeronautical Laboratories Aero Propulsion Laboratory, Wright-Patterson Air Force Base, Ohio. Dr. W. M. Roquemore of AFWAL/POSF was the Air Force Technical Monitor, and Dr. D. R. Ballal of Applied Physics Division, UDRI was the Principal Investigator of this research program. This report covers work performed during the period February 21, 1983 through October 20, 1987.

The tabulated data were compiled by D. R. Ballal, T. H. Chen, and W. J. Schmoll. We wish to express our gratitude and appreciation to

W. M. Roquemore for his help, advice, and encouragement;

J. Stutrud (AFWAL/POSF) for his assistance with computer software;

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SECTION 1
INTRODUCTION

Computer models that predict turbulent mixing and combustion processes in practical combustion systems suffer from numerous limitations, deficiencies, and errors. This has created an urgent need for a bench-mark quality data base to validate and refine these models. With that broad goal in mind, the U. S. Air Force Wright Aeronautical Laboratories, Aero Propulsion Laboratory (AFWAL/PO) in early 1983 initiated a five-year program of research with the University of Dayton Research Institute (UDRI). This program had three principal objectives: (1) to develop a combustion test facility and optical diagnostics; (2) to perform turbulent mixing and combustion experiments; and (3) to provide a data base for modeling needs.

In Volume I of this final report, experimental studies on turbulent mixing and combustion were described. Volume II contains bench-mark quality data recorded in these experiments. Specifically, data are tabulated for three variable-density, non-reactive turbulent mixing experiments: (1) 2-D Mixing Layer, (2) 2-D Slot Jet/Centerbody, and (3) Round Jet; and two turbulent combustion experiments: (1) Scalar Fluctuations in Premixed Flames, and (2) Conical Flame Stabilizer Experiment.

All data were obtained in the Fundamental Combustion Laboratory Facility located in Building 490, Room 153 of AFWAL/PO, Wright-Patterson Air Force Base, Ohio. Most of the data were interpreted and published in a total of 22 papers in the open literature. The Appendix to Volume I of this final report lists all the publications.

Our format for data base documentation was developed as per the recommendations laid out in a report AFOSR-TR-85-0880 by

Strahle and Lekoudis [1]. Briefly, this report suggested the following requirements for data tabulation:

(1) Specify the test configuration and test conditions,

(2) Provide a set of inlet boundary conditions which include both mean and turbulence quantities,

(3) Provide a set of axial profiles of mean and turbulence quantities,

(4) Provide one or more sets of radial profiles of mean and turbulence quantities,

(5) Provide a set of data on complex turbulence parameters, viz turbulent scalar fluxes and joint velocity-scalar pdfs.

Accordingly, the experimental test configuration for each set of tabulated data is sketched on a page immediately preceding the respective data set. Test conditions and relevant references are also specified. This information is followed by the tabulation of inlet boundary conditions, axial profiles, radial profiles, and finally complex turbulence quantities. The measured turbulence quantities appear in the columns of individual tables.

In our experiments, axial and radial (or transverse) components of velocity were obtained with a two-component LDA. The principal dimensions of the LDA control volume were 30 μm x 200 μm, and the data sampling rates were as high as 8 kHz in cold flows and 3 kHz in flames. Scalar fluctuations were detected using a LRS system. Here, the measurement volume was made as small as 30 μm x 200 μm x 1000 μm. Sampling rates up to 5 kHz in cold flows and 1 kHz in low-temperature flames were possible. Measurements of turbulent scalar fluxes and joint pdfs of

velocity and scalar were made by optically and electronically integrating the LDA-LRS systems. Finally, a reactive Mie scattering (RMS) and a schlieren system were used for flow visualization in these experiments. No special or unusual methods, in addition to those described above, were employed.

The tabulated measurements spanned a period from 1984 through 1987. During these experiments, data were checked both for reproducibility and accuracy. The long-term repeatability of measurements at selected locations was within 3 percent for LDA, within 5 percent for LRS, and within 7 percent for the integrated LDA-LRS measurements. As for accuracy, both mass and momentum conservation tests were run, and these demonstrated that the calculations, mass flowmeter readings, and optical measurements agreed to within 4 percent to 7 percent, respectively.

These data tables may be used to evaluate and refine the various computer modeling codes of turbulent mixing and combustion.

SECTION 2
TURBULENT MIXING EXPERIMENTS

2.1 2-D Mixing Layer Experiment

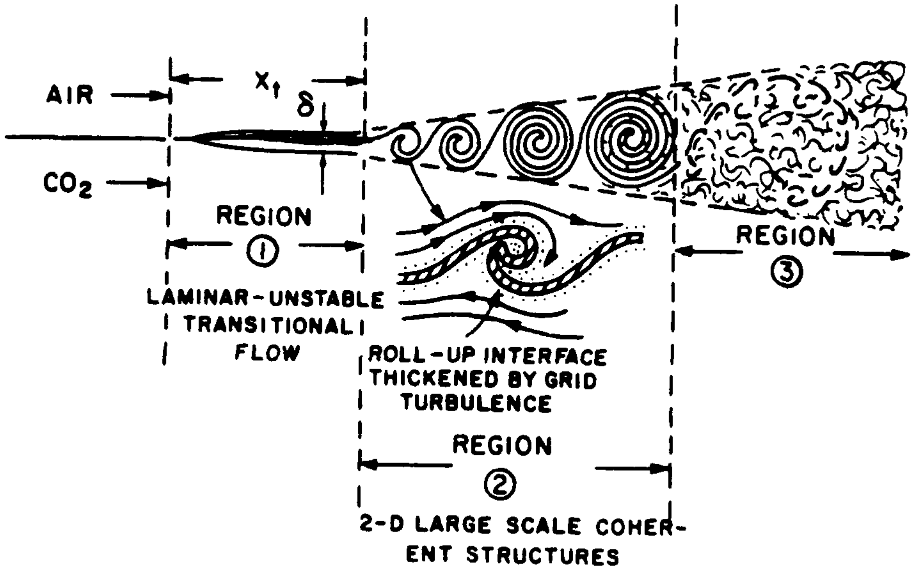

Figure 1. Development of a 2-D Mixing Layer Downstream of a Splitter Plate.

Test Conditions

(a) Flow parameters:

(1) U_1 = 1.8 m/s, U_2 = 1.2 m/s, $\bar{U}$ = 1.5 m/s, $U/\bar{U}$ = 0.4, δ_0 = 0.25 cm, X_t= 4.2 cm, Re_{x_t} = 1605, δ_t= 0.76 cm, Re_{δ_t} = 305

(2) U_1 = 2.1 m/s, U_2 = 0.9 m/s, $\bar{U}$ = 1.5 m/s, $U/\bar{U}$ = 0.8, δ_0 = 0.25 cm, X_t = 2.2 cm, Re_{x_t} = 1681, δ_t = 0.4 cm, Re_{δ_t} = 290

(b) Specifications of turbulence grids:

	Coarse grid(CG)	Fine grid(FG)
Mesh, (mm)	2.54	16/in.
Diameter, (mm)	1.9	0.4
Open area, (%)	51	56
$u'/\bar{U}$, (%)	8	2.2
L, (mm)	6	2.3
λ, (mm)	1.8	1.3

Laminar flow existed with no grid present.

Table 1

Inlet Boundary Conditions.

(a) Mean Quantities

D = 1 cm, x/D = 0.15, z/D = 0, (1) air, (2) CO_2, No grid

y/D	$\Delta U/\bar{U} = 0.40$			$\Delta U/\bar{U} = 0.80$		
	U/U_1	U/U_2	C/C_1	U/U_1	U/U_2	C/C_2
0	0.180	0.220	0.85	0.201	0.241	0.870
0.1	0.830	0.874	0.88	0.950	0.88	0.920
0.2	0.975	0.963	0.98	1.047	1.100	0.975
0.3	1.045	0.980	1.0	1.101	1.150	1.0
0.4	1.120	1.100	1.0	1.190	1.20	1.0
0.5	1.100	1.120	1.0	1.108	1.273	1.0
0.6	1.053	1.040	1.0	1.001	1.105	1.0
0.7	1.010	1.010	1.0	0.925	1.087	1.0
0.8	0.980	1.003	1.0	0.915	1.010	1.0
0.9	0.880	0.950	1.0	0.873	0.665	1.0
1.0	0.301	0.416	1.0	0.373	0.330	1.0

Table 1
(Continued)

(b) Turbulence Quantities

$D = 1$ cm, $x/D = 0.15$, $z/D = 0$, $\Delta U/\bar{U} = 0.80$

(1) - air (2)-CO_2, All values are in percent

NG - No grid, FG - Fine Grid, CG - Coarse Grid

y/D	No Grid		Fine Grid	Coarse Grid		
	u'/U_1	u'/U_2	u'/U_1	u'/U_1	u'/U_2	u'/v'
0	0.18	0.22	1.02	8.21	0.41	0.96
0.1	0.23	0.31	1.83	8.11	0.31	1.18
0.25	0.47	0.55	2.23	7.6	0.55	0.97
0.37	0.58	0.48	2.81	6.85	0.48	1.10
0.50	0.60	0.65	2.32	8.33	0.65	1.12
0.63	0.52	0.43	2.43	8.76	0.42	1.24
0.75	0.48	0.33	1.90	6.75	0.33	1.07
0.87	0.62	0.38	2.25	7.32	0.38	1.18
1.00	0.41	0.40	2.72	7.81	0.40	1.21

Table 1
(Concluded)

(c) Mean Values Along the Edge of the Splitter Plate
$x/D = 0.15$, $y/D = 0.0$, $\Delta U/U = 0.40$

z/D	U/U_0	C/C_0	u'/u'_0	c'/c'_0
-0.5	0.33	0.25	1.14	1.21
-0.4	0.91	0.78	1.12	1.07
-0.3	0.98	0.98	1.0	1.0
-0.2	1.0	1.02	1.04	1.05
-0.1	1.04	1.02	1.07	1.10
0	1.00	1.00	1.0	1.0
0.1	1.07	1.00	1.03	1.07
0.2	1.03	1.00	1.04	1.0
0.3	0.90	0.97	1.0	1.04
0.4	0.85	0.78	1.07	1.13
0.50	0.25	0.28	1.17	1.23

Table 2

Concentration Fluctuations in Axial Direction.
y/D = z/D =0
All values of (c'/$\bar{C}$ are in percent)

x/D	$\Delta U/\bar{U}$ = 04			$\Delta U/\bar{U}$ = 0.8		
	NG	FG	CG	NG	FG	CG
0.15	7.5	-	-	8.2	-	-
0.50	10.2	10.8	11	13.1	12.0	18.0
1.0	16.2	16.3	16	15.0	15.5	22.5
1.5	18.1	19.1	20.1	21.0	20	25.5
2.0	25.3	23.2	21.2	26.2	28	28.5
2.5	26.2	24.5	22.1	28.1	30	28
3.0	27.5	26.7	23.2	30.2	31.2	27.3
3.5	28.0	26.5	24.2	28.3	27	26.1
4.0	28.5	27.0	25.7	27.0	26.5	25.5
4.5	28.5	27.0	25.2	27.5	25.3	24.2
5.0	28.0	27.5	24.0	25.0	24.2	23.2
5.5	27.3	27.0	24.0	24.3	24.1	21.5
6.0	26.8	26.5	23.5	23.3	23.5	20.3

Table 3

Mixing Layer Thickness in Axial Direction.
All Values of δ are in mm

x/D	$\Delta U/\bar{U}$ = 04			$\Delta U/\bar{U}$ = 0.8		
	NG	FG	CG	NG	FG	CG
0.15	2.5	-	-	2.5	-	-
0.5	2.5	2.6	2.6	2.5	2.6	2.7
1.0	2.6	2.8	3.0	3.0	3.2	3.5
1.5	3.1	3.2	3.5	3.1	3.5	4.0
2.0	3.3	4.0	5.0	4.1	4.2	5.1
2.5	3.7	4.3	5.5	4.5	5.2	6.5
3.0	4.0	5.0	6.5	5.5	6.0	6.8
3.5	5.0	5.5	7.5	6.5	7.0	8.0
4.0	6.5	7.3	11	7.3	8.2	10.0
4.5	7.8	8.5	12	8.7	9.5	11
5.0	9.5	11.2	14	11.2	12.5	14
5.5	12.0	13	15	12.5	13.7	15
6.0	13.0	15	17	14	15.2	17.5

Table 4

Eddy Spacing in Axial Direction.
Eddy spacing time scale in msec.

x/D	ΔU/Ū = 04			ΔU/Ū = 0.8		
	NG	FG	CG	NG	FG	CG
0.15	-	-	-	-	-	-
0.5	7.0	8.2	8.5	7.1	7.5	8.1
1.0	7.0	8.1	8.6	8.1	8.0	8.0
1.5	7.5	8.0	8.0	8.0	7.9	7.8
2.0	7.4	8.0	9.0	8.3	8.0	7.9
2.5	8.0	8.1	7.9	9.1	8.0	8.0
3.0	8.0	8.1	8.2	8.5	8.0	8.1
3.5	8.1	8.2	8.5	8.0	8.5	8.5
4.0	8.0	7.8	8.1	8.0	8.7	9.3
4.5	7.9	7.9	8.0	7.8	8.0	8.8
5.0	7.8	8.3	8.0	7.7	7.9	8.3
5.5	8.0	8.1	8.1	9.0	7.8	8.1
6.0	8.0	8.2	7.8	8.3	8.0	8.5

Table 5

Pdf of Concentration in Axial Direction.
Values of P(c) at $\Delta U/\bar{U} = 0.8$, $y/D = z/D = 0$

C \ x/D	0.5	2.5	4.5	5.5	6.0	7.0
0	-	2.2	3.3	4.3	1.20	1.3
0.1	0.12	2.0	2.7	0.5	0.75	1.1
0.2	0.21	1.7	3.5	1.5	2.1	3.0
0.3	0.25	1.0	2.4	2.3	3.0	4.2
0.4	0.80	1.0	1.0	3.0	3.8	3.2
0.5	4.0	2.0	0.35	2.7	4.2	2.5
0.6	3.5	2.7	0.25	2.0	3.7	2.2
0.7	1.5	3.0	0.20	1.0	2.8	1.9
0.8	0.5	2.5	2.8	1.0	1.75	1.5
0.9	0.25	1.4	3.3	1.7	0.70	0.83
1.0	0.0	0.50	3.8	2.0	0.41	0.50

Table 6

Pdf of Velocity in Region 2,
$\Delta U/\bar{U} = 0.8$, $x/D = 4.5$
P(c) is expressed in fraction of samples/ΔU

U	P(c)	U	P(c)	U	P(c)
0.6	0	0.85	4.5	1.1	0.50
0.65	0.1	0.90	5.5	1.15	0.25
0.70	0.25	0.95	3.5	1.20	0.20
0.75	0.75	1.00	2.5	1.25	0.10
0.80	2.5	1.05	1.2		

Table 7

Mixedness M(x) in Axial Direction.
$y/D = z/D = 0$

x/D	$\Delta U/\bar{U}$ = 04			$\Delta U/\bar{U}$ = 0.8		
	NG	FG	CG	NG	FG	CG
0.15	0.90	-	-	0.88	-	-
0.50	0.80	0.78	0.75	0.85	0.67	0.68
1.0	0.72	0.70	0.70	0.75	0.65	0.65
1.5	0.67	0.65	0.63	0.67	0.62	0.62
2.0	0.63	0.62	0.62	0.60	0.55	0.55
2.5	0.55	0.58	0.62	0.55	0.52	0.52
3.0	0.52	0.53	0.60	0.50	0.50	0.50
3.5	0.50	0.52	0.62	0.50	0.52	0.55
4.0	0.50	0.53	0.63	0.50	0.55	0.57
4.5	0.50	0.53	0.65	0.48	0.55	0.60
5.0	0.52	0.55	0.65	0.52	0.50	0.62
5.5	0.55	0.57	0.66	0.53	0.57	0.65
6.0	0.57	0.60	0.67	0.50	0.57	0.67

2.2 2-D Slot Jet/Centerbody Experiment

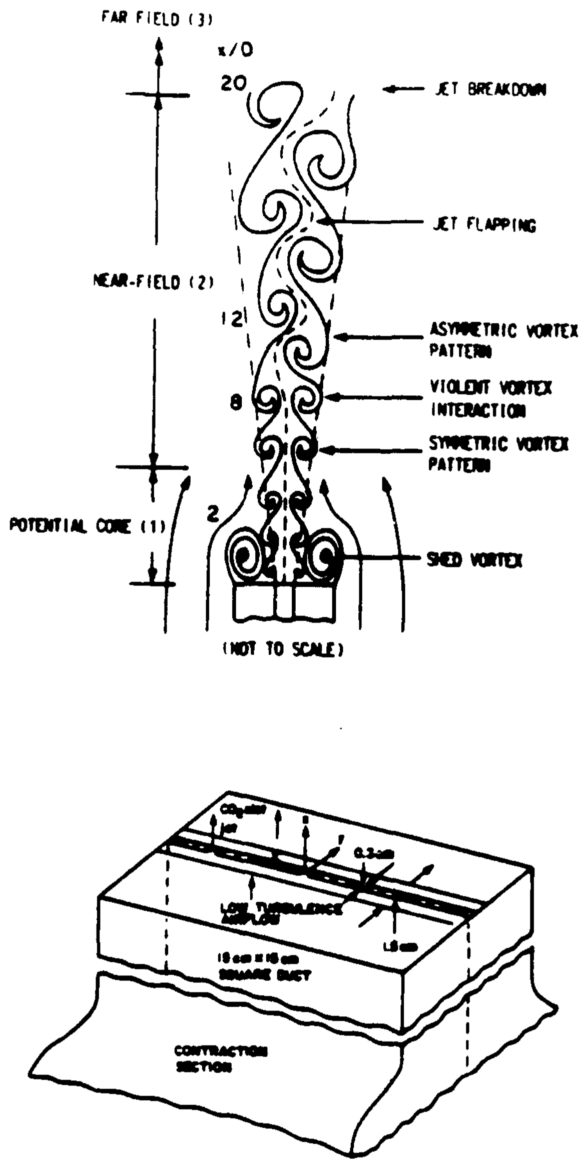

Figure 2. Sketch Illustrating (a) Flow Structure of a 2-D Slot Jet/Centerbody Configuration (b) 2-D Slot Jet/Centerbody Configuration.

Test Conditions

Slot width = 3 mm, Slot aspect ratio = 50, U_j = 3 m/s, Re_j = 1200, U_a = 0.3 m/s, Density ratio = 1.5, x/D up to 30.

Table 8

Inlet Boundary Conditions.

(a) Mean Quantities at x/D = 1.0, z/D = 0

y/D	$\frac{U-U_a}{U_j-U_a}$	V/U_j	y/D	C/C_j
0	1.0	-0.01	0	1.0
0.5	0.8	-0.01	0.1	0.98
1.0	-0.2	-0.007	0.2	0.95
1.5	-0.25	-0.008	0.3	0.90
2.0	-0.175	-0.007	0.4	0.85
2.5	-0.10	-0.005	0.5	0.80
3.0	-0.05	-0.002	0.6	0.50
3.5	-0.025	0.0	0.7	0.30
4.0	-0.01	0.0	0.8	-
4.5	-0.005	0.0	0.9	-
5.0	0.0	0.0	1.0	-

Table 8
(Concluded)

(b) Turbulence Quantities at $x/D = 1$, $z/D = 0$
All values are in percent.

y/D	u'/U_j	v'/U_j	c'/C_j	$\overline{uv}/U_j^2$
0	2.5	1	2.5	0.5
0.2	5	2.5	5.3	1.5
0.4	7.2	5.0	7.5	4.1
0.6	12.5	7.4	12.8	6.1
0.8	18	14	16.2	4.4
1.0	12.8	5.0	2.8	3.1
1.2	5.0	3.3	2.1	2.1
1.4	3.2	2.8	1.8	1.6
1.6	2.5	1.5	-	1.3
1.8	2.0	1.0	-	1.1
2.0	1.8	1.0	-	0.72

Table 9

(a) Axial Variation of Mean Quantities.
$y/D = z/D = 0$

x/D	$(U-U_a/U_j-U_a)$	C/C_j	r_u/D	r_c/D
0	0.82	0.65	0.55	1.5
5	0.75	0.60	0.80	1.7
10	0.65	0.55	1.7	2.5
15.	0.60	0.48	2.2	3.4
20	0.55	0.40	3.4	3.8
25	0.50	0.37	4.2	4.5
30	0.40	0.33	4.5	5.2
35	0.37	0.30	4.8	5.5
40	0.33	0.30	5.1	6.0
45	0.31	0.28	5.5	6.8
50	0.30	0.25	6.3	7.6
55	0.28	0.25	7.0	8.5
60	0.25	0.23	7.6	-

Table 9
(Concluded)

(b) Axial Variation of Turbulence Quantities.
$y/D = z/D = 0$

x/D	S	K	Sc_t
0	-1.0	2.5	0.40
5	-2.5	8.7	0.45
10	-1.7	5.5	0.65
15	-0.08	5.0	0.68
20	-0.05	3.7	0.70
25	-0.08	4.0	0.70
30	-1.0	4.0	0.70
35	-	-	0.72
40	-	-	0.70
45	-	-	-
50	-	-	-
55	-	-	-
60	-	-	-

Table 10

(a) Radial Variation of Mean Quantities.

y/D	x/D = 8			x/D = 30			
	$\frac{U-U_a}{U_J-U_a}$	V/U_j	C/C_j	$\frac{U-U_a}{U_j-U_a}$	S	K	C/C_j
0	0.8	0.35	0.60	0.37	-0.2	5.0	0.33
0.5	0.20	0.25	0.61	0.35	-0.5	3.3	0.30
1.0	0.0	0.10	0.60	0.33	-0.8	3.0	0.28
1.5	-0.1	0.50	0.55	0.25	-0.8	2.9	0.25
2.0	-0.1	0.02	0.40	0.22	-0.6	2.8	0.22
2.5	-0.08	0.10	0.30	0.15	-0.5	3.2	0.20
3.0	-0.08	0.15	0.20	0.10	-0.35	4.0	0.15
3.5	-0.05	0.20	0.15	0.08	0.15	4.5	0.10
4.0	-.0.02	0.22	0.10	0.05	0.0	5.0	0.08
4.5	-0.01	0.25	0.08	0.02	0	4.8	0.07
5.0	0.00	0.26	0.075	0.0	0	5.2	0.05

Table 10
(Concluded)

(b) Radial Variation of Turbulence Quantities.
All values are in percent.

	x/D = 8				x/D = 30			
y/D	u'/U_j	v'/U_j	c'/C_j	$\overline{uv}/U_j^2$	u'/U_j	v'/U_j	c'/C_j	$\overline{uv}/U_j^2$
0	16	16	17.5	4.1	11.2	7.5	7.1	2.5
0.5	17	20	18	6.2	10.5	8.1	6.5	4.1
1.0	19	23.5	20.1	8.5	10.1	8.2	6.2	5.1
1.5	18	25	21.5	9.1	9.5	8.5	6.1	5.5
2.0	16.5	13	20.5	8.5	9.1	9.0	5.5	6.1
2.5	10.2	5	16.3	6.2	8.2	8.8	5.1	7.0
3.0	4.1	2	12.2	2.8	7.1	7.5	4.7	6.0
3.3	3.3	1.7	7.5	1.5	6.5	7.1	3.5	5.3
4.0	2.2	1.0	5.3	1.1	3.5	6.5	2.5	4.1
4.5	1.5	1.0	2.5	0.81	2.4	6.0	1.5	3.2
5.0	1.0	1.0	2.0	0.72	2.0	5.1	1.0	2.7

Table 11

Radial Variation of Complex Turbulence Quantities.
(Velocity in m/s)

	x/D = 16				x/D = 30			
y/D	$\overline{uc}$	$\overline{vc}$	y/D	Sc_t	$\overline{uc}$	$\overline{vc}$	y/D	Sc_t
0	0.035	0.015	0	0.75	0.01	-0.025	0	0.68
1	0.040	0.06	0.5	0.70	0.015	-0.01	0.5	0.58
2	0.037	0.08	1.10	0.57	0.02	0.0	1.0	0.55
3	0.030	0.06	1.5	0.57	0.025	0.022	1.5	0.57
4	0.028	0.045	2.0	0.65	0.028	0.026	2.0	0.61
5	0.015	0.015	2.5	0.62	0.030	0.028	2.5	0.65
6	0.013	0.010	3.0	0.61	0.028	0.025	3.0	0.70
7	0.010	0.0			0.025	0.020		
8	0	-			0.015	0.018		
9	-	-			0.010	0.015		
10	-	-		0	0	0		

2.3 Round Jet Experiment

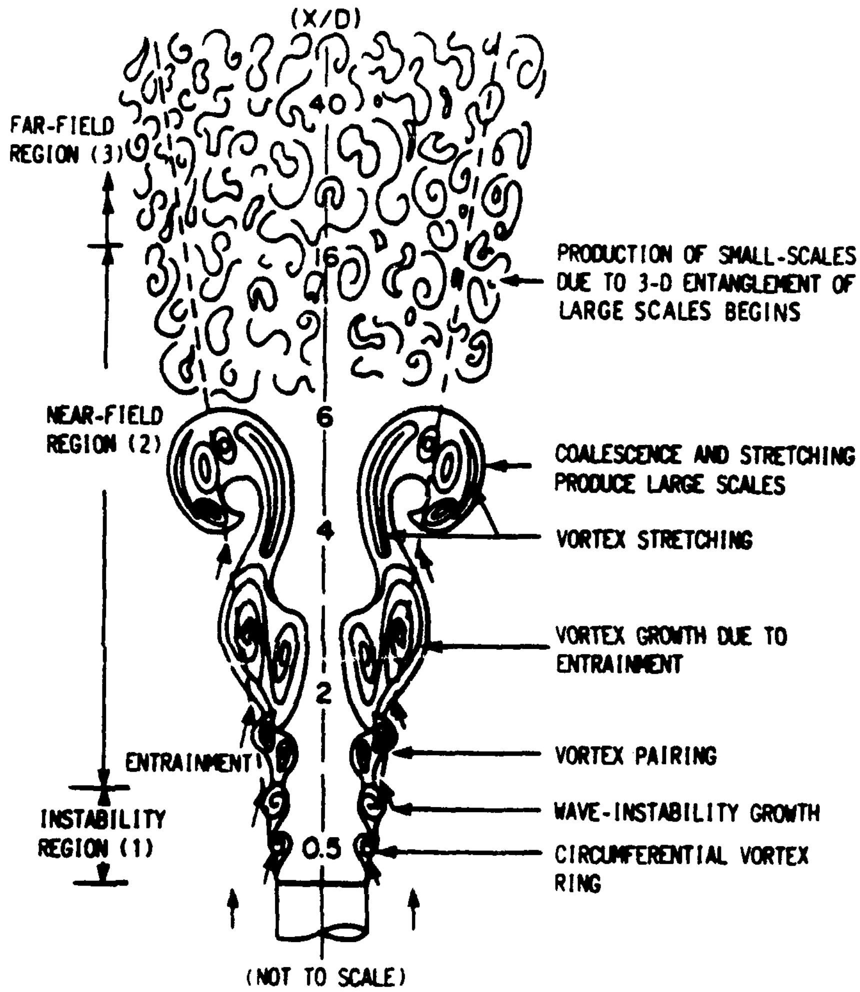

Figure 3. Turbulent Flow Structure of an Axisymmetric Round Jet.

Test Conditions

(a) Low-turbulence coflowing airstream:

Nozzle diameter = 1 cm, U_j = 8 m/s, U_a = 2 m/s, Re_j = 7600, $U/\bar{U}$ = 1.2, $\bar{U}$ = 5 m/s, Jet and coflowing air turbulence at the nozzle exit are 0.75 percent and 0.5 percent respectively.

(b) High-turbulence coflowing airstream:

Specifications of turbulence grid: Mesh size = 4.75 mm, Hole diameter = 3.55 mm, Open area = 51%, turbulence intensity = 6%, turbulence integral scale = 5 mm.

Table 12

Inlet Boundary Conditions.
(a) Mean Quantities

	x/D = 0.3			x/D = 4		
r/D	$(U-U_a/U_j-U_a)$	V/U_j	C/C_j	$(U-U_a/U_j-U_a)$	V/U_j	C/C_J
0	1.0	0.25	1.0	1.0	0.27	0.80
0.25	1.0	0.20	0.90	0.90	0.25	0.72
0.50	0.0	0	0.10	0.50	0.20	0.51
0.75	-0.15	-0.1	0.05	0.10	0	0.22
1.0	-0.10	-0.05	0	-0.05	0.05	0.03
1.25	-0.05	0	0	-0.025	0.025	0
1.50	-0.03	-0.01	-	-0.01	0.01	0
1.75	-0.01	-0.01	-	0	0	0
2.0	0	0	-	0	0	-
2.25	0	0	-	-	-	-
2.50	0	0	-	-	-	-

Table 12
(Concluded)

(b) Turbulence Quantities
All values are in percent.

	x/D = 0.3				x/D = 4.0			
r/D	u'/U_j	v'/U_j	c'/C_j	$\overline{uv}/U_j^2$	u'/U_j	v'/U_j	c'/C_j	$\overline{uv}/U_j^2$
0	1.1	0.85	-	0.7	7.5	3.5	9	3.2
0.25	1.5	1.2	-	1.1	10.2	7.5	12	5.1
0.5	3.1	2.5	3.5	3.2	15.5	14.1	16.3	10.2
0.75	2.5	2.2	1.0	-1.0	12.5	10.3	17.2	7.5
1.0	1.7	1.3	-	-0.81	6.5	3.5	6.4	2.5
1.25	1.25	1.0	-	-0.41	2.5	2.2	2.5	1.5
1.50	1.1	0.8	-	0	2.1	1.8	0.5	0.51
1.75	1.0	0.85	-	0	1.75	1.5	-	0.47
2.0	0.95	0.81	-	0.78	1.50	1.2	-	0.76
2.25	1.0	0.75	-	1.1	1.25	1.1	-	1.1
2.50	1.0	0.80	-	1.3	1.2	1.0	-	1.0

Table 13

Axial Variation of Jet Spreading Rate.
(FST: Freestream Turbulence)

x/D	Low FST r_u/D	Low FST r_c/D	High FST $(U-U_a/U_j-U_a)$	High FST C/C_j	High FST r_u/D	High FST r_c/D
0	0.5	0.55	1.0	1.0	0.40	0.61
2	0.51	0.60	1.0	0.95	0.53	0.65
4	0.52	0.65	0.95	0.80	0.55	0.67
6	0.55	0.70	0.90	0.67	0.60	0.70
8	0.60	0.75	0.80	0.60	0.64	0.82
10	0.71	0.92	0.75	0.53	0.71	0.93
12	0.85	1.0	0.61	0.42	0.80	1.0
14	0.90	1.1	0.54	0.35	0.91	1.12
16	1.0	1.15	0.50	0.32	0.95	1.15
18	1.1	1.20	0.44	0.30	1.10	1.20
20	1.20	1.30	0.40	0.28	1.15	1.25

Table 14

(a) Radial Variation of Mean Quantities.

	x/D = 8				x/D = 16			
r/D	$(U-U_a/U_j-U_a)$	C/C_J	S	K	$(U-U_a/U_j-U_a)$	C/C_J	S	K
0	0.90	0.65	0.10	3.1	0.55	0.375	0.22	3.2
0.25	0.82	0.50	0.15	3.0	0.51	0.33	0.21	3.3
0.50	0.55	0.40	0.22	3.2	0.45	0.31	0.25	3.3
0.75	0.30	0.32	0.31	4.75	0.33	0.27	0.24	3.1
1.0	0.12	0.15	0.15	3.3	0.27	0.22	0.28	3.0
1.25	0.0	0.10	0.10	3.5	0.22	0.14	0.21	3.1
1.50	0.0	0.05	0.05	3.1	0.13	0.12	0.22	3.3
1.75	-	0.0	0.05	3.3	0.05	0.14	3.00	
2.0	-	-	0.04	3.2	0.02	0.0	0.13	3.0
2.25	-	-	0.04	3.2	0.0	0.0	0.10	3.2
2.50	-	-	0.03	3.1	0.0	-	0.10	3.1

Table 14

(b) Radial Variation of Turbulence Quantities.
All values are in percent.

	x/D = 8				x/D = 16			
r/D	u'/U_j	v'/U_j	c'/C_j	$\overline{uv}/U_j^2$	u'/U_j	v'/U_j	c'/C_j	$\overline{uv}/U_j^2$
0	9.1	7.5	11.2	2.5	8.6	7.2	7.1	2.5
0.25	11	10.2	10.5	7.2	9.2	7.5	7.5	3.3
0.50	12.5	10.5	10.8	7.5	9.5	7.0	7.8	5.2
0.75	11.5	7.4	10.3	6.2	9.3	7.8	8.2	6.4
1.0	10.2	6.2	8.3	4.1	8.2	6.2	8.2	5.0
1.25	8.5	3.5	5.2	1.0	7.5	3.5	8.0	4.3
1.50	5.1	2.7	2.5	0	6.2	2.7	7.5	2.5
1.75	3.5	2.1	2.0	1.1	4.3	2.1	5.2	2.1
2.0	2.5	1.8	0.53	1.5	2.6	1.75	2.5	1.3
2.25	2.1	1.75	0.25	1.5	2.4	1.75	2.0	1.0
2.50	2.0	1.8	0.0					
1.7	2.2	1.5	1.0	1.0				

Table 15

Radial Variation of Complex Turbulence Quantities.
(Velocity in m/s)

	x/D = 8			x/D = 16		
r/D	$\overline{uc}$	$\overline{vc}$	Sc_t	$\overline{uc}$	$\overline{vc}$	Sc_t
0	0.05	0.11	0.55	0.09	0.02	0.70
0.25	0.08	0.11	0.60	0.13	0.075	0.74
0.50	0.12	0.13	0.62	0.14	0.083	0.80
0.75	0.14	0.12	0.67	0.15	0.090	0.82
1.0	0.13	0.09	0.72	0.15	0.05	0.85
1.25	0.075	0.05	0.71	0.125	0.026	0.85
1.50	0.042	0.022	0.72	0.075	0.020	0.80
1.75	0.025	0.015	0.73	0.025	0.010	0.825
2.0	0.013	0.013	0.75	0.010	0.075	0.82
2.25	0.012	0.010	0.75	0.015	0.070	0.83
2.50	0.010	0.010	0.83	0.010	0.075	0.80

Table 16

Correlations of Joint Radial Velocity-Concentration Pdf's
x/D = 4, r/D = 5

V(m/s)	C_1	C_2	C_3	C_4
-2.4	0.22	-	-	-
-1.8	0.44	-	-	-
-1.8	0.0	0.17	-	-
-1.2	0.50	0.37	0.27	-
-1.2	0.0	0.0	0.05	0.11
-0.6	0.50	0.40	0.33	0.23
-0.06	0.0	0.0	0.048	0.08
0	0.55	0.44	0.32	0.22
0	0.0	0.03	0.050	0.11
0.6	0.58	0.38	0.22	-
0.6	0.0	0.05	-	-
1.2	0.60	-	-	-
1.2	0.11	-	-	-
1.8	0.60	-	-	-
1.8	0.22	-	-	-
2.4	0.58	-	-	-
2.4	0.40	-	-	-

Table 17

Inlet Boundary Conditions in the Presence of Free-Stream Turbulence.

(a) Mean Quantities

	x/D = 0.3			x/D = 4.0	
r/D	$(U-U_a/U_j-U_a)$	V/U_j	C/C_j	S	K
0	1.0	0.30	1.0	0	3.0
0.25	0.95	0.25	0.90	0.05	3.2
0.50	0.20	0.10	0.25	0.10	3.3
0.75	-0.05	-0.10	0.07	0.10	3.0
1.0	-0.025	-0.05	0	0	3.0
1.25	-0.01	-0.025	0	0	3.0
1.50	0	0	0	0	3.2
1.75	0	-	0	0.10	3.3
2.0	-	-	-	0.50	3.0
2.25	-	-	-	0	3.0
2.50	-	-	-	0	3.0

Table 17
(Concluded)

(b) Turbulence Quantities
All values are in percent.

	x/D = 0.3				x/D = 4.0			
r/D	u'/U_j	v'/U_j	c'/C_j	$\overline{uv}/U_j^2$	u'/U_j	v'/U_j	c'/C_j	$\overline{uv}/U_j^2$
0	2.2	1.3	0	0	7.5	3.4	13.2	2.2
0.25	3.2	2.1	1.2	2.1	13.3	10.2	14.5	7.1
0.50	7.5	5.3	6.1	0	15.2	13.5	15.3	10.3
0.75	6.1	5.1	2.2	0	12.5	12.3	12.6	8.4
1.0	6.2	5.0	0.5	-	9.2	8.2	7.7	4.3
1.25	5.1	4.5	0	-	7.5	7.1	3.3	10.3
1.50	5.1	4.5	0	1.2	6.2	5.5	2.6	10.0
1.75	5.0	4.1	-	1.1	4.5	4.1	2.2	8.1
2.0	5.3	4.2	-	1.0	4.1	3.5	1.7	1.3
2.25	5.1	4.1	-	1.0	3.7	2.4	1.2	1.0
2.50	5.0	4.1	-	10	3.5	2.5	1.0	1.0

Table 18

Radial Variation of Turbulence Quantities.

x/D = 80

All values except those for S and K are in percent.

r/D	v'/U_j	c'/C_j	$\overline{uv}/U_j^2$	S	K
0	9.5	12.3	5.2	0	3.1
0.25	10.7	12.0	6.3	0.10	3.3
0.50	11.4	12.7	7.5	0.15	3.0
0.75	10.2	12.5	6.1	0.10	3.0
1.0	6.5	9.2	5.2	0.10	3.2
1.25	5.3	7.5	2.5	0.13	3.3
1.50	4.2	5.3	2.2	0.14	3.0
1.75	3.3	3.5	2.3	0.10	3.2
2.0	3.0	2.3	2.1	0.10	3.1
2.25	3.0	2.0	2.1	0	3.2
2.50	-	2.0	2.0	0	3.0

Table 19

Axial Variation of Turbulent Scalar Flux $\overline{vc}$.

x/D	$\overline{vc}$
0	0
2	0.15
4	0.13
6	0.122
8	0.105
10	0.09
12	0.085
14	0.082
16	0.08
18	-
20	-

Table 20

Radial Variation of Complex Turbulence Quantities.

	x/D = 4.0		x/D = 8.0		
r/D	$\overline{uc}$	$\overline{vc}$	$\overline{uc}$	$\overline{vc}$	Sc_t
0	-0.04	0.0	0.005	0.003	-
0.25	-0.03	0.015	0.010	0.005	0.65
0.50	-0.015	0.03	0.017	0.015	0.70
0.75	-0.03	-0.01	0.021	0.017	0.75
1.0	-0.01	0.0	0.015	0.0125	0.78
1.25	0	0	0.005	0.010	0.79
1.50	0	0	0.004	0.013	0.78
1.75	-	-	-	-	0.80
2.0	-	-	-	-	0.80
2.25	-	-	-	-	0.82
2.50	-	-	-	-	0.85

Table 21

Correlations of Joint Radial Velocity-Concentration Pdfs
$x/D = 4,\ r/D = 0.5$

v(m/s)	C_1	C_2	C_3
-2.10	0.22	-	-
-1.80	0.40	-	-
-1.80	0.05	-	-
-1.50	0.44	-	-
-1.50	0.0	0.20	-
-1.20	0.42	0.30	-
-1.20	-0.10	0.08	-
-09.0	0.50	0.32	-
-0.90	-0.10	0.0	0.11
-0.60	0.53	0.33	0.15
-0.60	-0.17	0.0	0.12
-0.30	0.50	0.31	0.17
-0.30	-0.17	0.01	0.11
0.0	0.50	0.30	0.20
0.0	-0.15	0.05	-
0.3	0.50	0.20	-
0.3	0.0	-	-
0.6	0.48	-	-
0.6	-0.10	-	-
0.9	0.48	-	-
0.9	0.11	-	-
1.2	0.33	-	-
1.2	-	-	-

Table 22

Spectral Development of the Round Jet
in an Axial Direction.
(α_o and α_s are the normalized amplitudes of fundamental and sub-harmonic frequencies respectively)

x/D	α_o	α_s	St_θ	St_D	Comments
0	-	-	0.01	0.55	Nozzle exit
0.5	0.50	0.10	0.015	0.51	
1.0	1.1	0.125	0.021	0.50	Vortex roll-up
1.5	0.75	0.37	0.032	0.45	
2.0	0.52	0.50	0.040	0.42	Vortex pairing
2.5	0.37	0.62	0.042	0.38	
3.0	0.25	0.81	0.050	0.35	Non-linear region
3.5	0.18	0.95	0.060	0.33	($x/D > 2$)
4.0	0.10	1.0	0.072	0.32	Vortex merging
4.5	0.10	0.95	0.085	0.31	
5.0	0.08	0.90	0.12	0.30	Axisymmetric instability
5.5	0.077	0.84	0.13	0.30	mode dominant
6.0	0.075	0.80	0.152	0.30	
6.5	0.075	0.75	0.15	0.33	
7.0	0.075	0.70	0.17	0.30	
7.5	0.075	0.60	0.17	0.30	
8.0	0.075	0.45	0.18	0.31	
8.5	-	0.37	0.18	0.32	
9.0	-	0.13	0.18	0.30	Helical instability
9.5	-	-	0.18	-	mode dominant
10.0	-	-	-	-	

SECTION 3

TURBULENT COMBUSTION EXPERIMENTS

3.1 Scalar Fluctuations in a Premixed Flame

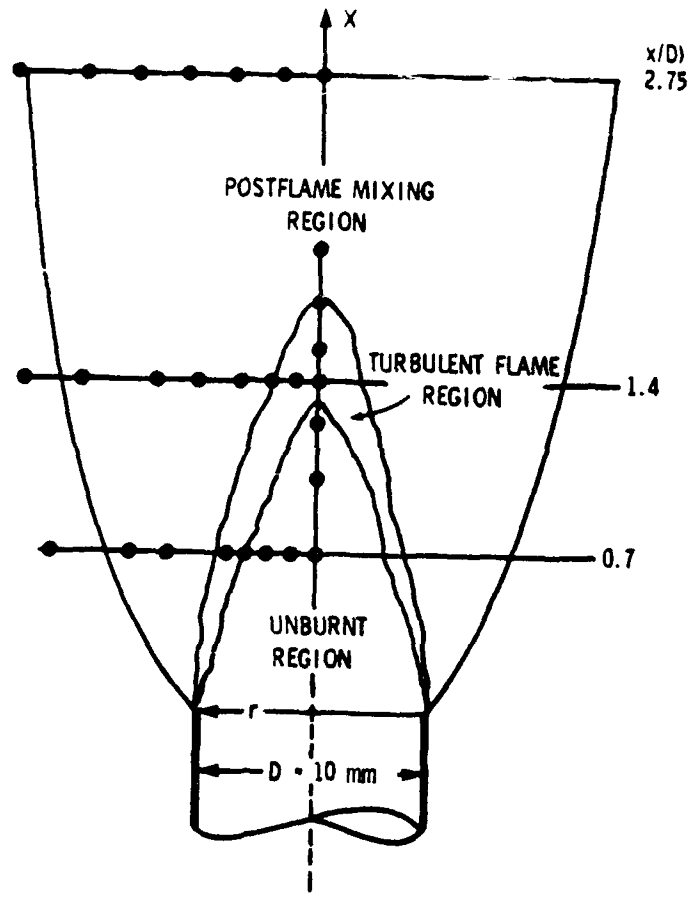

Figure 4. Turbulent Premixed Flame Illustrating the Various Regions and the Locations for Measuring Scalar and Velocity Fluctuations.

Test Conditions

Premixed methane-air flame

Nozzle Diameter = 1 cm, $\bar{U}$ = 2 m/s, $u'/\bar{U}$ = 18%, L = 4 mm, Equivalence ratio, ϕ = 1.4, T_f = 1880 K, S_L = 20 cm/s, τ = 6.5, u'/S_L = 2, $L/\delta_r \gg 1$.

Table 23

Temperature Profile Through the Flame in Axial Direction.
$r/D = 0$

x/D	$\bar{T}/T_f$
0.0	-
0.5	0.21
0.75	0.25
1.0	0.31
1.25	0.63
1.50	0.82
1.75	1.00
2.0	1.00
2.25	0.97
2.50	0.98
2.75	0.95
3.0	0.84

Table 24

Radial Profile of Mean Velocity and Temperature
$x/D = 1.4$

r/D	$\bar{U}/U_c$	$\bar{T}/T_f$
0	1.0	0.66
0.13	0.97	0.71
0.25	0.95	0.76
0.37	0.91	0.85
0.50	0.85	0.91
0.67	0.80	0.87
0.75	0.76	0.76
0.87	0.65	0.62
1.00	0.51	0.52
1.13	0.44	0.36
1.25	0.40	0.30

Table 25

Axial Profile of Turbulence Quantities.
r/D = 0, D = 1 cm

x/D	$u'/\bar{U}$ (%)	T'/T_f (%)	L_u/D	L_T/D
0	-	-	-	-
0.25	-	-	-	-
0.50	17.5	2.5	-	0.31
0.75	18.2	5.4	0.15	0.38
1.0	18.3	10.0	0.27	0.40
1.25	18.5	13.5	0.41	0.45
1.50	19.3	34.7	0.44	0.51
1.75	18.5	16.2	0.52	0.44
2.0	18.0	153	0.55	0.41
2.25	17.5	14.2	0.53	0.36
2.50	17.2	13.7	0.55	0.33
2.75	16.8	13.2	0.54	0.34
3.0	17.0	13.5	0.53	0.35

Table 26

Radial Profile of Turbulence Quantities.
x/D = 1.4

r/D	u'/U(%)	T'/T_f(%)	λ_T/D
0	18.3	24.1	0.31
0.13	17.2	23.4	0.32
0.25	17.0	20.2	0.32
0.37	15.3	15.3	0.30
0.50	16.1	16.5	0.31
0.67	15.8	17.3	0.29
0.75	15.8	15.5	0.28
0.87	16.0	17.6	0.27
1.00	17.5	18.5	0.26
1.13	17.2	18.2	0.26
1.25	15.3	18.0	0.26

Table 27

Variation of Scalar Fluctuations and Dissipation Through the Flame .

$\tilde{c}$	T'/T_f	$\bar{\chi}_u/\bar{\chi}_{uc}$	$\bar{\chi}_u/\bar{\chi}_t$
0	-	-	-
0.1	0.130	0.10	0
0.15	0.21	0.18	0.075
0.20	0.32	0.22	0.11
0.25	0.33	0.30	0.13
0.30	0.30	0.42	0.22
0.35	0.33	-0.45	0.27
0.40	0.29	0.62	0.42
0.45	0.275	0.63	0.45
0.50	0.28	0.66	0.55
0.55	0.25	0.67	0.63
0.60	0.23	0.71	0.60
0.65	0.21	0.71	0.62
0.70	0.18	0.70	0.63
0.75	0.17	0.70	0.60
0.80	0.15	0.73	0.62
0.85	0.10	0.67	0.58
0.90	0.10	0.60	0.46
0.95	0.050	0.50	0.38
1.00	-	0.45	0.30

Table 28

Pdf of Temperature Through the Flame.
r/D = 0 P(T) is given in 10^{-2}/K

x/D = 0.7		x/D = 1.4				x/D = 2.0	
T(K)	P(T)	T(K)	P(T)	T	P(T)	T(K)	P(T)
250	0.05	350	-	1450	4.3×10^{-2}	1300	0
275	0.20	400	5×10^{-2}	1500	3.0	1350	4×10^{-2}
300	0.72	450	5.5	1550	3.2	1400	5.5
325	0.85	500	6.2	1600	3.2	1450	7.8
350	0.42	550	6.5	1650	3.5	1500	9.0
375	0.15	600	8.2	1700	4.0	1550	12.2
400	0.10	650	7.5	1750	6.5	1600	14.2
425	0.05	700	8.1	1800	10.5	1650	18.3
450	0.001	750	9.2	1850	11.3	1700	14.5
		800	9.5	1900	10.5	1750	12.0
		850	10	1950	4.2	1800	10.50
		900	10.5	2000	3.3	1850	9.5
		950	11.3	2050	2.2	1900	10.1
		1000	9.7	2100	1.2	1950	10.5
		1050	9.5	2150	1.2	2000	9.3
		1100	8.2	2200	-	2050	-
		1150	7.5			2100	-
		1200	6.0			2150	-
		1250	6.5			2200	-
		1300	7.7				
		1350	8.6				
		1400	6.5				

3.2 Conical Flame Stabilizer Experiment

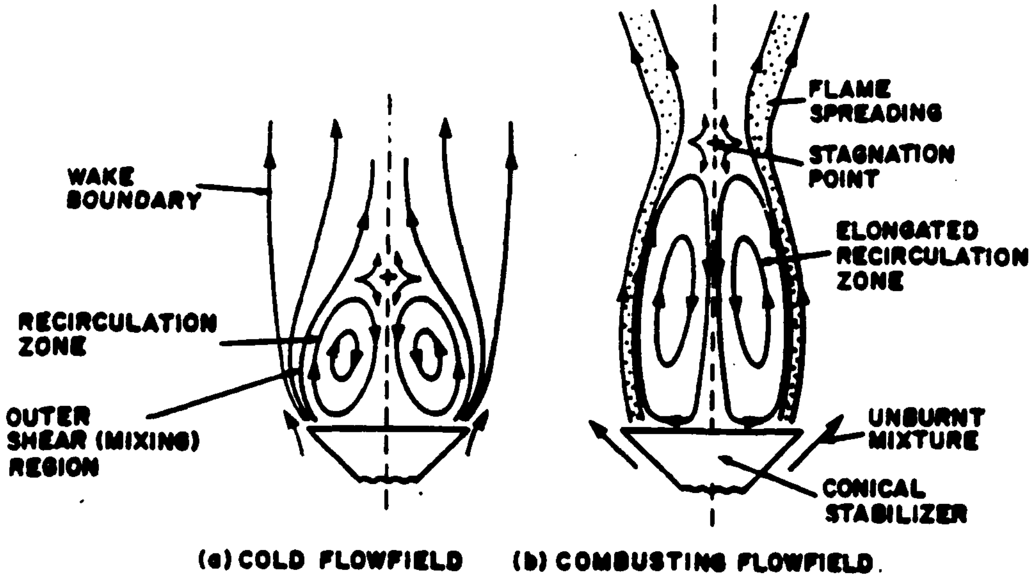

Figure 5. Structure of the Recirculation Zone Downstream of a Conical Flame Stabilizer Without and With Combustion.

Test Conditions

Premixed methane-air mixture

Stabilizer base diameter = 4.44 cm, Length = 3.81 cm,
Apex angle = 45^{o}, Blockage ratio = 31%,
U_a = 10 m/s, Re_d = 2.85×10^4, u'/U = 4%, v'/U = 2.8%.
Equivalence ratio = 0.80, T_f = 1870 K,

Table 29

Inlet Boundary conditions

(a) Mean Quantities

$x/D = 0.05,\ z/D = 0$

	Cold Flow		Combustion			
r/D	U/U_a	V/U_a	U/U_a	V/U_a	S	K
0	-0.051	0	-0.10	0	0.03	3.1
0.11	-0.025	0.07	-0.075	0.10	0	3.0
0.22	-0.025	0.10	-0.075	0.15	0	3.3
0.33	0.0	0.12	-0.050	0.21	-0.05	2.9
0.44	0.05	0.14	0	0.22	-0.25	3.4
0.55	0.90	0.14	0.90	0.15	0.75	3.6
0.66	0.95	0.12	1.0	0.20	0	2.8
0.77	0.975	0.12	1.0	0.10	0.03	3.2
0.88	-	-	1.0	0.10	0.03	3.1
1.00	-	-	1.0	-		

Table 29
(Concluded)

(b) Turbulence Quantities

x/D = 0.05, z/D = 0

All values are in percent.

	Cold Flow			Combustion		
r/D	u'/U_a	v'/U_a	$\overline{uv}/U_a^2$	u'/U_a	v'/U_a	$\overline{uv}/U_a^2$
0	12.5	14.3	-5.3	8.2	17.2	0
0.11	11.8	15.8	5.2	8.0	16.1	10.3
0.22	10.3	16.4	10.7	7.4	15.3	15.4
0.33	9.5	17.3	25.4	8.5	13.5	22.3
0.44	9.5	18.2	30.2	18.3	11.3	30.2
0.55	16.2	13.2	-47.3	10.4	25.2	-31.4
0.66	2.5	5.3	0	4.8	2.5	-40.5
0.77	3.3	6.8	30.2	3.5	3.3	20.7
0.88	7.5	9.4	35.3	9.3	7.5	22.4
1.00	-					

Table 30

Centerline of Mean and Turbulence Quantities
Along the Axis.
All turbulence quantities are given in percent.

	Cold Flow				Combustion			
x/D	U/U_a	u'/U_a	v'/U_a	$\overline{uv}/U_a^2$	U/U_a	u'/U_a	v'/U_a	$\overline{uv}/U_a^2$
0	0	10.5	-	-5.3	0	10.2	16.5	-2.3
0.25	-0.3	12.4	10.0	-3.2	-0.40	14.5	10.4	-1.2
0.50	-0.42	15.3	17.5	0	-0.44	14.4	10.5	0
0.75	-0.32	13.5	20.3	0	-0.60	12.4	11.2	0
1.0	-0.11	13.3	25.2	0	-0.62	10.3	12.5	0
1.25	0.20	12.7	24.5	2.5	-0.65	10.0	12.4	1.3
1.50	0.50	12.2	21.2	1.4	-0.45	10.2	12.5	2.2
1.75	0.60	12.0	18.3	2.2	-0.20	10.2	13.2	0
2.0	0.65	12.2	17.5	0	-0.10	10.5	14.5	0
2.25	0.70	11.4	15.5	0	0	11.5	14.0	1.4
2.50	0.72	11.5	14.3	2.2	0.20	12.3	13.2	2.2
2.75	0.75	11.2	12.5	1.3	0.35	11.4	12.4	0
3.0	0.775	11.2	11.4	0	0.42	12.2	12.5	0
3.25	0.780	11	11.7	0	0.45	12.4	12.0	0
3.50	0.80	10.6	10.5	0	0.60	13.3	11.3	0

Table 31

Radial Profiles of Mean and Turbulence Quantities in the Vicinity of the Stagnation Point. (x/D = 2.0) All turbulence parameters are in percent.

	Cold Flow			Combustion		
r/D	U/U_a	u'/U_a	v'/U_a	U/U_a	u'/U_a	v'/U_a
0	0.45	13.2	22.6	-0.25	11.3	13.3
0.11	0.52	14.1	21.3	-0.21	11.0	14.1
0.22	0.55	15.5	19.5	-0.22	15.4	15.0
0.33	0.70	16.3	13.3	0	20.0	15.3
0.44	0.74	12.5	9.5	0.30	22.3	13.5
0.55	0.8	11.3	7.4	0.50	17.5	10.2
0.66	0.85	7.4	8.3	0.82	11.4	9.3
0.77	0.70	14.3	10.5	1.0	7.5	8.5
0.88	0.50	15.5	10.0	0.95	10.2	10.2
1.00	-					

Table 32

Radial Profiles of Reynolds Shear Stress, Skewness, and Kurtosis in the Vicinity of the Stagnation Point (x/D = 2.0)

	Cold Flow			Combustion		
r/D	$\overline{uv}/U_a^2$ (%)	S	K	$\overline{uv}/U_a^2$ (%)	S	K
0	0	0	3.2	0.0	0.25	3.0
0.11	-20.3	0.05	3.1	-30.5	0.22	2.9
0.22	-45.2	-0.25	3.0	-55.5	0.23	2.8
0.33	-50.0	-0.70	3.3	-60.2	0.10	2.8
0.44	-30.5	-0.90	3.0	-53.2	-0.25	3.1
0.55	0	-0.94	3.9	-50.2	-0.40	3.1
0.66	20.5	-0.85	3.8	-25.3	-0.53	3.2
0.77	30.2	-0.25	3.0	20.2	-0.24	3.5
0.88	35.3	0.10	3.0	35.3	0.10	3.4
1.0	-	-	-			

SECTION 4
CONCLUDING REMARKS

Developing a bench-mark quality data base for evaluating and refining modeling codes of turbulent mixing and combustion represents a significant experimental challenge. Clearly, this work was a multifaceted effort involving fluid mechanics, combustion, spectroscopy, computer software development, and data interpretation. Skills and interests of several individuals were brought together, and a series of experiments were completed over an extended period of time and as per the recommendations of AFOSR report number TR-85-0880.

Our work complements the experiments of Dibble and coworkers [2-4] at the Combustion Research Facility, Sandia National Laboratories, Livermore, CA. First, we tested a variety of flow configurations (e.g., mixing layer, slot jet, and a conical flame stabilizer) in addition to the round jet. Second, we employed unique test conditions (grid-generated turbulence, centerbody surrounding the slot jet, thick flame fronts, etc.) in our experiments. Third, to simplify the development of computer modeling codes, the axial pressure gradients in our flowfields were negligible. Finally, to assist the development of direct numerical simulation type of modeling codes [5,6] our experiments were performed in the range of Reynolds number lower than those of Dibble and coworkers [2-4]. Thus, our measurements together with those of Dibble and coworkers now provide a complete spectrum of data sets of interest to modelers.

We hope that these data sets will find widespread use in evaluating, refining, and developing modeling codes of turbulent mixing and combustion.

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NOMENCLATURE

BR	Blockage ratio
$\underset{\sim}{C}$	Concentration of CO_2 (c-fluctuating value)
c	Progress variable
D	Jet/Burner diameter, slot width, base diameter
d	Hole diameter
E	Energy
f	Frequency
K	Kurtosis
L	Integral length scale
M(x)	Mixedness parameter
P	Probability density function
Re	Reynolds number
r	Radius, radial direction
S	Burning velocity, Skewness
Sc_t	Turbulent Schmidt number
St	Strouhal number
T	Temperature
t	Time
U, V, W	Mean velocities, (u, v, w - fluctuating values)
Δ	Mean velocity defect
$\overline{uv}$	Reynolds shear stress
$\overline{uc}$, $\overline{vc}$	Turbulent scalar fluxes
x, y, z	Axial, transverse, and azimuthal directions
α	Spectral amplitude
δ	Mixing layer, Flame front thickness
ϕ	Equivalence ratio
λ	Turbulence microscale
θ	Momentum thickness

τ	Heat release rate parameter
ρ	Density
ν	Kinematic viscosity

Superscript

$\bar{}$	Mean value
$'$	Rms value
$\tilde{}$	Favre-averaged value

Subscript

1, 2	Air, CO_2 streams respectively
a	Outer, Annulus airstream
f	Flame
i, o	Initial, fundamental value
j	Jet exit value
L,t	Laminar, turbulent value
r	Reaction zone
s	Subharmonic value
T	Temperature
u, v	Velocities
θ	Momentum thickness

Abbreviations

LDA	Laser Doppler Anemometer
LRS	Laser Raman/Rayleigh Spectroscopy

CG	Coarse grid
FG	Fine grid
NG	No grid
FST	Freestream Turbulence
Pdf	Probability density function
Psdf	Power spectral density function

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